SHOCK-INDUCED SUBSOLIDUS REDUCTION-DECOMPOSITION OF ORTHOPYROXENE
AND SHOCK-INDUCED MELTING IN NORITE 78235; C. B. Sclar and J. F. Bauer, Dept.
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Lunar rock 78235,44 is a shocked coarse-grained (3-5mm) norite with a relict subophitic texture(1). It is composed of about equal proportions of chromian bronzite (En_{78}Fs_{19}Wo_{3}) and plagioclase (An_{95-98}). It appears to be the only true norite of deep-seated crustal origin in the returned lunar samples and has been interpreted as a plagioclase-orthopyroxene cumulate(2). Most of the plagioclase is now maskelynite and the residual crystalline plagioclase is highly deformed and contains fine shock lamellae. The larger pyroxene grains are characterized by shock-induced mosaic structure and planar deformation features, and many of the original pyroxene grains were brecciated and comminuted.

The bronzite contains (wt %) 0.5 Cr_{2}O_{3}, 1.3 Al_{2}O_{3}, 0.2 TiO_{2}, and 0.25 MnO. Locally, it was transformed to a heterogeneous intimately intergrown four-phase assemblage: metallic iron, chromite, diopside, and silica. The transformed regions occur as irregular patches up to 400μm in size which are either localized at specific sites along orthopyroxene-plagioclase grain boundaries or appear as isolated ameboid areas within the orthopyroxene. Some of the transformed regions within the orthopyroxene have the form of anastomosing veinlets independent of cleavage which appear to reflect pre-existing fractures. The transformed regions consist of highly irregular anhedral grains of metallic iron, chromite, and diopside disseminated non-uniformly through a matrix of silica. The chemical composition of the minerals which constitute the largest patch of transformed orthopyroxene was determined with the electron microprobe. This patch, which is enclosed within orthopyroxene, contains a large irregular area of homogeneous metal (250x100μm) with the composition (in wt %) 95.4 Fe, 2.6 Co, and 2.1 Ni. The shape of the metal particle suggests that it was localized at the intersection of several cracks in the orthopyroxene. Contiguous with the metal is an area of silica of about the same size through which are disseminated minute particles of metallic iron, irregular anhedral grains of magnesian aluminian chromite (in wt % 59.1 Cr_{2}O_{3} and 0.38 MnO; in mole % 82.8 FeCr_{2}O_{4}, 12.9 MgAl_{2}O_{4}, 3.4 Mg_{2}TiO_{4}, and 0.9 FeV_{2}O_{4}), and highly irregular grains of clinopyroxene with the composition range Di_{83}Hd_{17} - Di_{90}Hd_{10} which contain <0.05%A1, Cr, Mn, Ti, and V. The silica is virtually pure (>98%SiO_{2}), but it may contain a small amount of iron (ca. 1%) and perhaps calcium (0.2%). There are no detectable gradients of Mg and Fe in the host pyroxene surrounding the transformed region.

Qualitatively at least it is possible to account for all of the elements in the original orthopyroxene through their mineralogical expression in the transformed regions. The textural relationships and phase chemistry of the assemblage metal-silica-chromite-diopside in which the metal is almost pure iron with Co>Ni support the hypothesis that this assemblage was derived from the orthopyroxene host by shock-induced transient heating to subsolidus temperatures up to about 1400°C which resulted in local breakdown of the bronzite and reduction of its Fe^{2+} to Fe^{0}. The sporadic distribution of the transformed regions and their apparent localization at grain boundaries and cracks

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are also in accord with the concept that shock-related thermal spikes, which tend to be localized at grain boundaries and cracks (3, 4), might initiate non-equilibrium high-temperature reduction and breakdown of the bronzite.

Trollite occurs in the transformed regions in the orthopyroxene in the form of tiny dispersed anhedral grains and discontinuous rims on grains of iron and chromite. This appears to be evidence for vapor-phase sulfurization of metal and chromite in the waning stages of a transient shock-heating event (5). Correspondingly, the occurrence of anhedral grains of chlorapatite within the large transformed region described above may record late-stage vapor transport of phosphorous and chlorine.

Locally, the plagioclase contains one to three sets of crystallographically oriented minute rods of metallic iron (up to 0.8 μm wide and 25 μm long). Similar oriented rods of iron have been observed in Luna 20 plagioclase (6, 7, 8) and plagioclase of troctolitic granulite 76535 (9). The plagioclase in 78235 contains 0.1 - 0.2 wt % FeO and it seems logical to conclude that the metallic rods are the result of exsolution and reduction of the Fe²⁺ originally incorporated in the plagioclase at high temperature. It is not clear, however, whether subsolidus reduction of Fe²⁺ in plagioclase occurred as the result of slow cooling of the original igneous rock or whether it occurred as the result of subsequent transient shock-heating. The nonuniform distribution of the metal rods in the plagioclase of this shocked norite leads one to suspect the latter.

An irregular vein which has a thickness as great as 350 μm cuts through the rock. It is developed dominantly along orthopyroxene-plagioclase grain boundaries and is only subordinately transgressive. The vein consists principally of crystalline components although some glass is present. Flow structures are revealed by refractive-index differences which reflect differences in composition of adjoining arcuate segments; the streaks of anorthosite composition consist of quench crystals of plagioclase whereas those of intermediate bulk composition between bronzite and anorthosite may be glass. The crystalline phases in the vein consist of fine feathery aggregates of plagioclase (quench crystals of composition An₉₆-₉₈), fine radial-fibrous aggregates of pyroxene with a very low birefringence, and partly melted xenocrysts of bronzite. The vein is interpreted as a shock-induced melt derived from the host norite; plagioclase was the major contributor, but the bronzite contributed some Mg and Fe to the melt. The quench crystals of plagioclase contain 0.5 - 1.2% FeO and 0.9 - 2.2% MgO whereas the large plagioclase of the norite contains only 0.1 - 0.2% FeO and < .05% MgO. The presence of both Fe and Mg in the lattice of the plagioclase crystallites is consistent with their interpretation as quench crystals from a high-temperature shock-produced melt of noritic composition. By comparison, crystallites of plagioclase formed in the quench from grain-boundary liquids of plagioclase composition produced by shock in anorthositic rock 60015 contain only 0.1% FeO and < .05% MgO (3). Correspondingly, one might expect the quench pyroxene in the vein to have an unusually high content of Al₂O₃ and CaO. Although it is possible that the radial-fibrous aggregates of quench pyroxene are intimately intergrown with quench plagioclase on a sub-optical scale, they appear to be single-phase at the resolution level of the optical microscope. On
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This basis, the quench pyroxene contains 25.5% Al$_2$O$_3$ and 13.6% CaO which corresponds to [Ca$_{0.5}$Mg$_{0.5}$Fe$_{1.8}$Al$_{1.2}$ (Si$_{1.7}$Al$_{0.3}$) O$_6$]. Such a composition is consistent with our interpretation of the pyroxene aggregates as quench crystals derived from a shock-induced melt.

Four mechanisms have thus far been proposed to explain the occurrence of metal on the moon. (1) metal of meteoritic origin expressed as fragments of meteorites (original textures typically destroyed by reheating) and metal spherules derived from meteorites by impact melting and vaporization, (2) metal of igneous origin resulting from crystallization of basic magmas on the moon, (3) metal produced by subsolidus reduction of opaque oxides and fayalite in igneous rocks through slow post-crystallization cooling, and (4) metal produced by reduction of Fe$^{2+}$ in impact melts of basaltic and anorthositic composition and by reduction of ilmenite xenocrysts immersed in basaltic impact melts. Based on our study of norite 78235, we now propose a fifth mechanism, namely, subsolidus reduction through transient shock-induced heating of Fe$^{2+}$-bearing silicates.


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